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PATENT APPLICATION

Inventors:	Prakash Gothoskar et al.		
Case	SIO-0105		
Patent No.	**6,897,498**	**Issue Date**	May 24, 2005
Serial No.	**10/772,724**	**Filed**	February 5, 2004
Examiner	Fetsum Abraham	**Group Art Unit**	2826
Title	**Polycrystalline Germanium-Based Waveguide Detector Integrated on a Thin Silicon-On-Insulator (SOI) Platform**		

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SIR:

REQUEST FOR CERTIFICATE OF CORRECTION UNDER RULE 1.323

In accordance with 37 CFR 1.323, the enclosed Certificate of Correction is submitted for consideration in the above-identified patent.

Column 6 line 5 should read as follows: $I_{ph} = \frac{q(1-R)P_{in}\lambda}{hc}(1-e^{-\alpha d})$

Also enclosed please find a check in the amount of **$100.00** to cover the fee as set forth under 37 CFR 1.20(a).

Respectfully submitted,

Prakash Gothoskar, et al.

By: Wendy W. Koba
Wendy W. Koba
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Reg. No. 30509
610-346-7112

Date: 11/8/2007

Encl. Letters Patent (portion to be corrected)
Certificate of Correction

PTO/SB/21 (11-07)
Approved for use through 11/30/2007. OMB 0651-0031
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TRANSMITTAL FORM

(to be used for all correspondence after initial filing)

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First Named Inventor	GOTHOSKAR
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Examiner Name	Fetsum Abraham
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ENCLOSURES *(Check all that apply)*

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  - [ ] Fee Attached
- [ ] Amendment/Reply
  - [ ] After Final
  - [ ] Affidavits/declaration(s)
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Remarks

SIGNATURE OF APPLICANT, ATTORNEY, OR AGENT

Firm Name	Wendy W. Koba		
Signature	Wendy W. Koba		
Printed name	Wendy W. Koba, Esq.		
Date	November 8, 2007	Reg. No.	30509

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610-346-7112
Telephone Number

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1. Certificate of Correction for Patent No. 6,897,498

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UNITED STATES PATENT AND TRADEMARK OFFICE
CERTIFICATE OF CORRECTION

PATENT NO. : 6,897,498

APPLICATION NO.: 10/772,724

ISSUE DATE : May 24, 2005

INVENTOR(S) : GOTHOSKAR, GHIRON, PATEL, MONTGOMERY, SHASTRI, PATHAK, YANUSHEFSKI

It is certified that an error appears or errors appear in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

Please correct column 6 line 5 to read as follows:

$$I_{ph} = \frac{q(1-R)P_{in}\lambda}{hc}(1-e^{-\alpha d})$$

MAILING ADDRESS OF SENDER (Please do not use customer number below):

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The present invention involves the confinement of light into silicon waveguides with very narrow dimensions (for example, height<1 μm, width~1 μm). The tight confinement of light enables the fabrication of detectors with very small dimensions. The narrow waveguide geometry also relaxes the limitation associated with the prior art large area detectors, such as the prior art arrangement of FIG. **1**. Material defects such as threading dislocations and small grain size adversely affect of the performance of the prior art detector. Techniques of the thin-film transistor industry, such as cyclic annealing and laser annealing, can be used to improve the quality of the poly-germanium material for better electrical and optical performance. Appropriate process control during the formation of the poly-germanium detector of the present invention allows for changing the dimensions of grain size and threading dislocations to improve detector performance in terms of lower dark current, increased carrier lifetime and higher mobility.

The poly-germanium material can also be doped with suitable dopants, such as boron for p-type doping or P, As or Sb for n-type doping, to create a lateral p-i-n structure. A p-i-n based photodetector can also be formed using appropriately positioned contacts (electrodes). For example, an undoped absorbing layer of germanium may be disposed between a p-type highly doped contact layer and an n-type highly doped contact layer. When a reverse bias is applied to the photodetector, the depletion region width increases, reducing the transit time of carriers. The optical mode propagating in the silicon waveguide of the SOI structure creates electron-hole pairs when interacting with the poly-germanium region. The electron-hole pairs are collected by the appropriately positioned electrodes. The collection efficiency depends upon the distance between the two electrodes, as well as the quality of the poly-germanium material.

The generation of electron-hole pairs is directly related to the absorption of light, since every absorbed photon generates one electron-hole pair. The optical generation rate g_{OP} is given by:

$$g_{op} = \left(\frac{\alpha P_{in}\lambda}{Ahc}\right)$$

where A is the illuminated area of the photodiode, P_{in} is the incident power, α is the absorption coefficient, h is Planck's constant, c is the velocity of light in a vacuum, and λ is the wavelength of light. As an example, using a poly-germanium detector having the dimensions of 1 μm×10 μm×0.2 μm, if an input light signal at λ=1.55 μm and power of 1 μW is absorbed into the detector, then the number of electron-hole pairs generated in the volume of the detector is equal to about 8×10^{13} cm^{-3}. Therefore, the thermally generated electron-hole pair concentration equals about 20. Due to the tight confinement of light, a significant amount of power is delivered to the poly-germanium detector, resulting in at least two orders of magnitude more electron-hole pairs compared to thermal generation.

Assuming all electron-hole pairs generated contribute to the photocurrent, the photocurrent can be given by the following integral:

$$I_{ph} = qA\int_{-xp}^{xn+d} g_{op}\,dx$$

where d is the thickness of the undoped region (which depletes), q is the electronic charge, and the integration is taken over the width of the depletion region. In all cases, the integral may be reduced to:

$$I_{ph}\frac{q(1-R)P_{in}\lambda}{hc}(1-e^{-\alpha d})$$

where R is the reflection at the interface of the waveguide and the detector. A near-IR wavelength light with λ=1.55 μm, P_{in}=1 μW and $\alpha=10^3$ cm^{-1} results in 1 μA of current for a 10 μm long detector. In the prior art, conventional dark currents on the order of 10^{-3} A/cm^2 have been reported for normal incidence detectors, such as that shown in FIG. **1**. In contrast, the expected dark currents for the poly-germanium-based waveguide detectors of the present invention (~10 μm^2) are on the order of 1 nA, resulting in a higher signal-to-noise ratio.

In most of the embodiments of the present invention, waveguide layer **16** will comprise one of three geometries: (1) slab, (2) strip, or (3) rib. FIGS. **3**(*a*) and (*b*) contain cross-sectional and isometric views, respectively, of a slab waveguide SOI-based structure. In this example, upper silicon waveguide layer is denoted $\mathbf{16}_{slab}$. The cross-sectional view of FIG. **3**(*a*) also illustrates an exemplary optical mode for a signal propagating along slab waveguide $\mathbf{16}_{slab}$. As a result of the sub-micron thickness of silicon slab waveguide $\mathbf{16}_{slab}$, an evanescent tail of the optical mode extends beyond waveguide layer $\mathbf{16}_{slab}$, making the mode very sensitive to both top surface **17** and bottom surface **19** of waveguide layer $\mathbf{16}_{slab}$. Advantageously, a poly-germanium detector may be disposed over top surface **17** of waveguide layer $\mathbf{16}_{slab}$ to capture that portion of the optical mode extending above top surface **17** of layer **16**.

FIGS. **4**(*a*) and (*b*) illustrate an exemplary photodetector of the present invention as used with a slab waveguide, where a poly-germanium layer **18** is disposed on top surface **17** of the SOI-based structure **10** of FIG. **3**. Also with reference to FIG. **2**, it is shown clearly in FIG. **4**(*a*) that the optical mode is coupled into poly-germanium layer **18**, allowing for absorption to take place. As shown, a pair of electrical contacts $\mathbf{20}_1$ and $\mathbf{20}_2$ are formed along opposing sides of layer **18**, where the amount of absorption will be controlled by the length of layer **18** along the lateral dimension of structure **10**. In one arrangement not illustrated, an array of such detectors can be formed upon the same waveguide layer $\mathbf{16}_{slab}$ and used to absorb different wavelengths propagating along the same layer $\mathbf{16}_{slab}$ (such as, for example, in a wavelength division multiplexed (WDM) communication system).

If it is desired to electrically isolate the detector from silicon waveguide layer $\mathbf{16}_{slab}$, a dielectric layer **22** (such as, for example, SiO_2) may be disposed to cover top surface **17** of waveguide layer $\mathbf{16}_{slab}$. FIGS. **5**(*a*) and (*b*) illustrate a cross-sectional view and isometric view, respectively, of such a structure. In most cases, this layer may be grown over the underlying silicon waveguide layer $\mathbf{16}_{slab}$. Alternatively, layer **22** may be deposited. It has been found useful to include a dielectric layer **22** in the photodetector structure of the present invention to simplify the process integration of introducing the poly-germanium detector layer **18** with the silicon waveguide layer **16**.

FIGS. **6**(*a*) and (*b*) contain a cross-sectional and isometric view, respectively, of a strip waveguide SOI-based structure. In this example, upper silicon strip waveguide layer is denoted $\mathbf{16}_{strip}$. The cross-sectional view of FIG. **6**(*a*) also illustrates an exemplary optical mode for a signal propagating along strip waveguide $\mathbf{16}_{strip}$. As a result of the sub-micron thickness and width of silicon strip waveguide